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Modern Fiber Optic Submarine Cable Telecommunication Systems Planning for Explosive Bandwidth Needs at Different Deployment Depths

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Abstract

The explosive bandwidth needs, especially in the inter data center market, have pushed transmission data rates to 100 Gbit/sec and beyond. Current terrestrial fibers are inadequate for long haul, high bandwidth deployments. To solve these problems a new fiber is introduced for terrestrial high bandwidth deployments: different polymeric core fibers with enlarged effective area with a significant optical signal to noise ratio improvement over other conventional terrestrial single mode fibers. To ensure the new fiber may be deployed robustly a new coating structure was employed. A rigorous cable structure was then chosen for evaluation. Based on experimental data, both the deep ocean water temperature and pressure are tailored as functions of the water depth. As well as the product of the transmitted bit rate and the repeater spacing is processed over wide ranges of the affecting parameters. It is taken into account the estimation of the total cost of the submarine fiber cable system for transmission technique under considerations. The system capacity as well as the spectral losses, and the dispersion effects are parametrically investigated over wide range ranges of the set of affecting parameters {wavelength, ocean depth (and consequently the ocean pressure and temperature), and the chemical structure}.

1 Introduction

The popularity of new high-bandwidth data services such as high-definition video and cloud storage has fueled a tremendous need for capacity growth across the entire telecommunication infrastructure. In recent years this has driven an industry-wide effort to develop the components, subsystems and systems required to upgrade networks to 100G line rates. From this, coherent-detected polarization-multiplexed (Bakhshi, et al, 2004), quadrature phase shift keying (CP-QPSK) has emerged as the industry-wide standard for 100 G transport. CP-QPSK modulation is based on coherent detection technology and digital signal processing, which offer many advantages including the compatibility with a 50-GHz channel grid (Mohamed, et al, 2011a), dispersion un-managed transmission and electronic polarization-mode dispersion compensation. 100G coherent transponder technology can be deployed both by upgrading existing 10G-optimized transmission systems, as well as through the Greenfield deployment of 100G-optimized overlay networks. An overlay network allows for the optimum transmission performance and therefore the most scalable and cost-effective approach towards large-scale 100G deployment, making this the preferred approach for most terrestrial networks. This avoids the additional complexity and transmission impairments that can occur when legacy networks with installed 10 G channels are upgraded with coherent technology. The capacity upgrade of submarine cable networks is significantly more challenging when compared to terrestrial networks. Greenfield deployment of a new submarine cable network is tremendously expensive and requires a long lead time for planning, certification and deployment. This has resulted in a surge of submarine line terminal equipment (SLTE) upgrades (Suzuki, et al, 2006) where legacy 10 G line terminals are replaced with 40 G transponder technology. More recently, experiments using re-circulating loop configurations have shown that with state-of-theart amplifier and fiber technology it is feasible to transmit 100 G line rates over the transmission distances of interest to submarine networks (Mohamed, et al, 2011b). However, to the best of our knowledge, no 100 G field trials on deployed submarine cables have been reported so far.

The first submarine network using erbium doped fiber amplifiers (EDFA) linking the United States with Europe, offered a total capacity of 10 Gbit/sec on two fibers, each with a single 5 Gbit/sec modulated wavelength (Charlet and Bigo, 2006). Very soon after, the WDM technique emerged, transmitting several wavelengths on a single optical fiber with increased aggregate transmission capacity and the opportunity of routing specific wavelengths via offshore branching units (Bigo, 2006). The first WDM transatlantic system in 1999, alcatel deployed the Apollo network in 2001, which can transmit 80 wavelengths per fiber, 6300 km across the Atlantic, modulated at 10 Gbit/sec. Recent laboratory experiments have demonstrated that system suppliers can now offer 6500 km long systems, providing a total capacity above 1 Pbit/sec (Lefrancois, et al, 2006), (128 x10 Gbit/sec WDM transmission per fiber in a cable with eight fiber pairs). This represents a 1000 fold capacity increase in just ten years over a transoceanic distance. The technology evolutions, which have enabled this capacity increase to take place, are the increase in the optical amplification bandwidth, the optimum management of fiber chromatic dispersion and transmission modulation format (Mohamed, et al, 2011c).

From the planning stage to the deployment of an undersea fiber-optic cable, a considerable amount of time, money and resources are invested to ensure the success of a submarine network. Yet one point that is often overlooked during this process, and which can lead to unfortunate delays [Pilipetskii, 2006; Bergano, 2005; and Mohamed, et al, 2011d), is the final acceptance test of the fiber—simply put, this comes down to making sure that the fiber can deliver on the promised and expected bandwidth. This final acceptance test is often ignored since legacy data rates are considered as being extremely challenging to transmit. Yet with the deployment of 40 G (Tang, 2001a), newer and more serious challenges are at hand, and in order to face them, they must be understood and properly prepared for. To do so, some critical physical-layer tests must be performed, including dispersion testing, such as chromatic dispersion (CD) and polarization mode dispersion (PMD). Tests that were considered as being of mild importance at 10 G, have become critical at 40G transmissions. Once these parameters have been fully qualified and optimized (Rashed, 2011a), the system turn-up tests must then be performed; this includes signal power level and optical signal-to-noise ratio (OSNR) measurements, which are important in both repeated transoceanic or festoon links. Finally, the network end-to-end level qualification must be done (Tang, 2001b; Fujisawa and Koshiba, 2004; and Rashed, 2011b); this is where all the relevant SONET/SDH tests are performed, including tests such as bit error rate (BER).

In the present study, the performance of high speed submarine optical fiber cable systems with wavelength division multiplexing is investigated, taking into account both the pressure and the temperature effects. Both the pressure and the temperature are depth-dependent variables, while both the spectral losses and the dispersion effects are temperature as well as wavelength dependent variables. It is found that the ocean pressure (due to the depth) shifts the dispersion-free wavelength towards the third communication window. In general, as the depth increases the maximum transmitted bit rate increases in the range of interest.

2 Mathematical Model Analysis

The pressure dependent Sellemeier coefficients and material dispersions for Poly methyl metha acrylate (PMMA), Polyhexafluoro isopropyl 2-fluoroacrylate dibutyl phathalate (PHFIP 2-FA-DBP), and Polyhexafluoro isopropyl 2-fluoroacrylate (PHFIP 2-FA) fibers, will be cast under the form (Ghosh and Yajima, 1998; and Fleming, 1984):

$$n^2(\lambda, T, P) = n^2(\lambda, T)\, f(P, \lambda) \quad ...(1)$$

Where n is the refractive index, λ is the optical signal wavelength, T is the ambient temperature in K, P is the pressure. Aoul-Enein (1989) cast the following:

$$n^2(\lambda, P) = A + \frac{B\lambda^2}{\lambda^2 - C} + \frac{K\lambda^2}{\lambda^2 - E} \quad ...(2)$$

With:

$$A = 1.2358792 + 6.385x10^{-5} P + 0.5345x10^{-7} P^2 \quad ...(3)$$

$$B = 0.25462 + 42.08x10^{-3} P - 1.71823x10^{-5} P^2 \quad ...(4)$$

$$C = 34.07945x10^{-3} - 0.56093x10^{-4} P + 0.8294313x10^{-8} P^2 \quad ...(5)$$

$$K = 0.917151 + 38.7911x10^{-6} P - 1.13552x10^{-8} P^2 \quad ...(6)$$

$$E = 15.0 \quad ...(7)$$

Where P is the pressure in MN/m^2. A special software is designed to handle Eqs. (1-7) to recast $n^2(\lambda, P)$ under the following form to account the thermal effects, recalling again Eq. 1 as follows: $n^2(\lambda, T, P) = n^2(\lambda, T)\, f(P, \lambda)$. Where f(P,λ) is found to possess the form:

$$f(P, \lambda) = 1 + R(P, \lambda) \quad ...(8)$$

Where:

$$R(P, \lambda) = A_1 + A_2\lambda + A_3\lambda^2 \quad ...(9)$$

and:

$$A_1 = 1.42407x10^{-3} + 1.29325x10^{-5} P - 5.25194x10^{-9} P^2 \quad ...(10)$$

$$A_2 = 2.47693x10^{-6} - 7.41884x10^{-7} P + 3.44237x10^{-9} P^2 \quad ...(11)$$

$$A_3 = 6.99036x10^{-6} + 1.96490x10^{-7} P - 1.044098x10^{-9} P^2 \quad ...(12)$$

With root mean square errors of A_1, A_2, and A_3 are 10^{-12}, 10^{-15}, and 10^{-23} respectively over the following ranges: 0.85 ≤ operating optical signal wavelength, λ, μm ≤1.55, 300 ≤ Pressure, P, MN/m^2 ≤ 600. The thermal-dependent refractive index n(λ,T) is cast on the same spirit of Aoul-Enein (1989):

$$n^2(\lambda, T) = \frac{B_1(T)\lambda^2}{\lambda^2 - Q_1^2(T)} + \frac{B_2(T)\lambda^2}{\lambda^2 - Q_2^2(T)} + \frac{B_3(T)\lambda^2}{\lambda^2 - Q_3^2(T)} \quad ...(13)$$

Where the Sellemeier coefficients for different three plastic fibers are listed in the following Table 1.

Table 1. Sellemeier coefficients for different polymeric materials based submarine transmission links (Mohamed, et al, 2011b; Mohamed, et al, 2011c; Rashed, 2011a; and Mohamed, et al, 2011e)
.

Coefficients	Polymeric Fibers		
	PMMA	PHFIP 2-FA-DBP	PHFIP 2-FA
B_1	0.4963	0.2680	0.4200
Q_1	0.6965 (T/T_0)	0.07913 (T/T_0)	0.05874 (T/T_0)
B_2	0.3223	0.3513	0.0461
Q_2	0.718 (T/T_0)	0.08381 (T/T_0)	0.08755 (T/T_0)
B_3	0.1174	0.2498	0.3484
Q_3	9.237 (T/T_0)	0.1062 (T/T_0)	0.09271 (T/T_0)

Where T_0 is the room temperature and is cast under the value of 300 K. Based on the data reported by Ref. [20], both the pressure P and the temperature, T in K, are correlated and the depth, D, as:

$$P = 29.942\,D - 0.05274\,D^2 + 56.5432x10^{-3}\,D^3, \quad \text{MN/m}^2 \text{ for } 10\,km \le D \le 90 \text{ km} \qquad ...(14)$$

and

$$T = 300 + .5423\,D + 0.095D^2 - 0.2045D^3, \text{ for } 10\,km \le D \le 90 \text{ km} \qquad ...(15)$$

and the temperature T is constant (T=constant) for D>90 km. Eq. 1 is the corner stone in the computation of the dispersion effects and consequently the system capacity, recall that:

$$\text{n}(\lambda,\text{T},\text{P}) = \text{n}(\lambda,\text{T})\sqrt{\text{f}(\lambda,\text{P})} = n(\lambda,T)F(\lambda,P) \qquad ...(16)$$

Where $\text{F}(\lambda,\text{P}) = 1.0 + 0.5\,\text{R}(\lambda,\text{P})$. Based on the models of Jeunhomme (1983) and Walker (1996), the total chromatic dispersion of a single mode fiber,τ, depends on n(λ,T,P) and its first and second derivatives $dn/d\lambda$ and $d^2n/d\lambda^2$ with respect to operating optical signal wavelength λ respectively where:

$$\frac{dn(\lambda,T,P)}{d\lambda} = n(\lambda,T)\frac{dF(\lambda,P)}{d\lambda} + \frac{dn(\lambda,T)}{d\lambda}F(\lambda,P) \qquad ...(17)$$

$$\frac{d^2n(\lambda,T,P)}{d\lambda^2} = n(\lambda,T)\frac{d^2F(\lambda,P)}{d\lambda^2} + \frac{d^2n(\lambda,T)}{d\lambda^2}F(\lambda,P) + 2\frac{dn(\lambda,T)}{d\lambda}\frac{dF(\lambda,P)}{d\lambda} \qquad ...(18)$$

For the step index single mode fiber waveguide dispersion, τ_{wg} is relatively small, so in this case the delay due to the chromatic dispersion equals the delay due to the material dispersion $\tau_{mat.}$ Which is given by Rashed (2011d), and (Enein, et al, 1989):

$$\tau = R_S\ \Delta\lambda\,|D_{mat}| \qquad ...(19)$$

Where R_S is the repeater spacing in km, $\Delta\lambda$ is the spectral line width of the optical source in nm, and $|D_{mat}|$ is the absolute value for material dispersion coefficient Which is given by the following equation:

$$D_{mat.} = -\left(\frac{\lambda}{c}\right)\left(\frac{d^2n(\lambda,T,P)}{d\lambda^2}\right), \qquad ...(20)$$

For standard single mode fiber, the transmitted signal bandwidth per transmitted channel can be determined as (Mohammed, et al, 2011e):

$$B.W_{sig.} = \frac{0.44}{\tau\,N_{ch}R_S}, \qquad ...(21)$$

The basic formula for a typical optical submarine link is an exponential decaying function as function of the repeater spacing, R_S as the following expression (Rashed,2011e):

$$P_R = P_T\,e^{-\alpha R_S} \qquad ...(22)$$

Where P_R is the received power after each repeater spacing through the lossy medium, P_T is the transmitted power, and α is the total attenuation coefficient of the submarine cable system. Based on MATLAB curve fitting program, the fitting equation between the attenuation, α in dB/km, and the water depth within the range of 10 km to 90 km at different optical single mode (SM) and multi mode (MM) fiber transmission windows can be given be the following formulas Walker (1996) and (Mohammed, et al, 2011f):

$$\alpha = 1.762 - 0.0359\,D + 0.00424\,D^2 ,\quad \text{(at 0.85 μm MM fiber)} \quad ...(23)$$

$$\alpha = 2.455 - 0.0534\,D + 0.00634\,D^2 ,\quad \text{(at 1.30 μm MM fiber)} \quad ...(24)$$

$$\alpha = 1.725 - 0.0368\,D + 0.0043\,D^2 ,\quad \text{(at 1.30 μm SM fiber)} \quad ...(25)$$

$$\alpha = 4.85 - 0.01063\,D + 0.0126\,D^2 ,\quad \text{(at 1.55 μm SM fiber)} \quad ...(26)$$

As well as the signal transmission quality, Q, of the submarine cable system can be estimated in dB units as [28]:

$$Q = 10\log \frac{P_T\, R_S}{NF\, K\, T\, \alpha} ,\quad \text{dB} \quad ...(27)$$

Where K is the Boltzmann's constant (1.38x10^{-23} J/K), P_T is the transmitted signal power, NF is the noise figure, and T is the ambient temperature. The bit error rate (BER) can be estimated from following Equation. The BER gives the upper limit for the signal because some degradation occurs at the submarine cable system end (Rashed, 2011g; and Rashed, 2011h).

$$BER = \frac{\exp\left(-0.5Q^2\right)}{Q\sqrt{2\pi}} \quad ...(28)$$

The submarine system must also satisfy the bandwidth requirements imposed by the rate at which data are transmitted. A convenient method of accounting for the bandwidth is to combine the rise times of the various system components and compare the result with the rise time needed for the given data rate and pulse coding scheme. The system rise time is given in terms of the data rate for non return to zero pulse code by Rashed, (2011i) and Rashed (2011j).:

$$B_R\,(NRZ) = \frac{0.7}{\tau} , \quad ...(29)$$

3 Simulation Results and Performance Analysis

In the following section, the transmission bit rate and transmission capacity product, will be parametrically processed with special emphasis on the depth of the ocean. Taking into account the variations of the under surface ocean pressure and temperature due to the ocean depth, a special software is cast to handle the relevant calculations namely: i) The ocean depth-pressure variations, ii) The ocean depth-temperature variations, iii) The transmitted bit-rate and product within non return to zero coding technique. Different three plastic optical fibers are employed toward the zone of minimum optical losses and dispersion. The reality of the processed calculations is considered via repeater spacing, R_S which is considered in the present case 600 km due to the amplifier gain. Based on the equations analysis and the assumed set of operating parameters listed in Table 2 as follows:

Table 2. Parameters for submarine cable telecommunication systems (Fujisawa and Koshiba, (2011); Aoul-Enein, (1989); and Rashed, 2011h).

Operating parameter	Value and units
Spectral linewidth of optical source, $\Delta\lambda$	0.1 nm
Room temperature, T_0	300 K
Optical transmitted power per channel, P_T	0.5 Watt
Repeater spacing, R_S	600 km
Operating optical signal wavelength, λ	$1.3\ \mu m \leq \lambda \leq 1.6\ \mu m$
Ocean water depth, D	$10 \leq D$, Km ≤ 90
Number of transmitted channels, $N_{ch(WDM)}$	100
Noise figure, NF	5 dB

Based on the series of the equations analysis, the set of the operating parameters listed in the above Table 2, and based on the set of the clarified figures (1-14), the following results are assured:

i) Figure 1. has assured that transmitted signal bandwidth increases with increasing ocean water depth for different polymeric materials based submarine fiber cable system under considerations. PHFIP 2-FA DBP polymeric material has presented the highest transmitted signal bandwidth compared to other materials under study.

ii) As shown in Figures (2-5) have demonstrated that received signal power decreases with increasing ocean water depth for different polymeric materials based submarine fiber optic cable at different optical transmission windows. It is observed that PHFIP 2-FA DBP polymeric material has presented the highest received signal power compared to other materials under the same operating conditions.

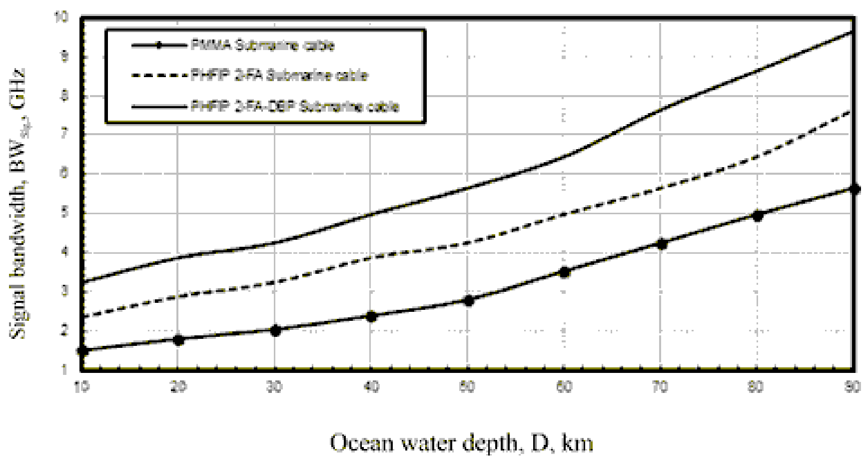

Figure 1. Transmitted signal bandwidth in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

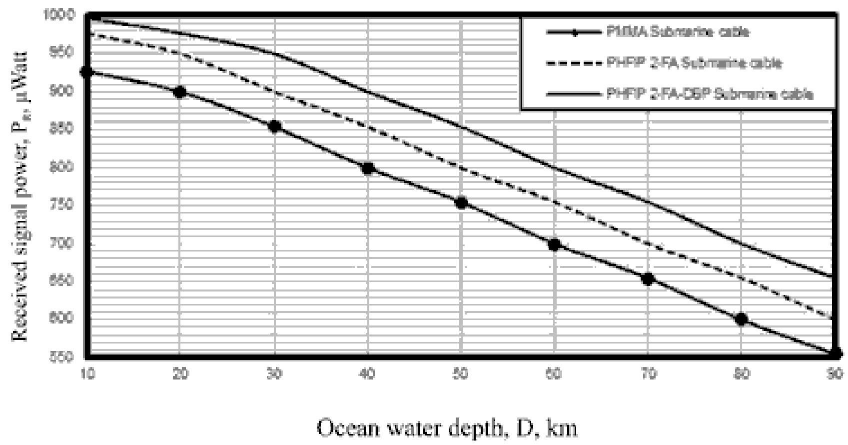

Figure 2. Received signal power in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

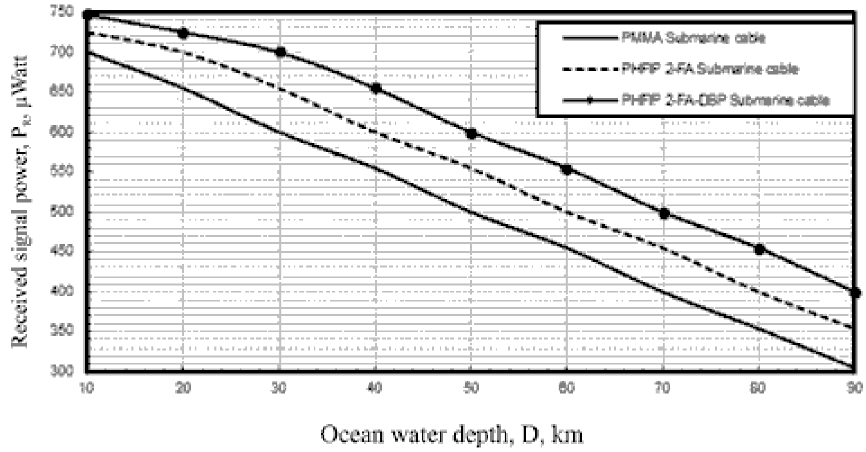

Figure 3. Received signal power in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

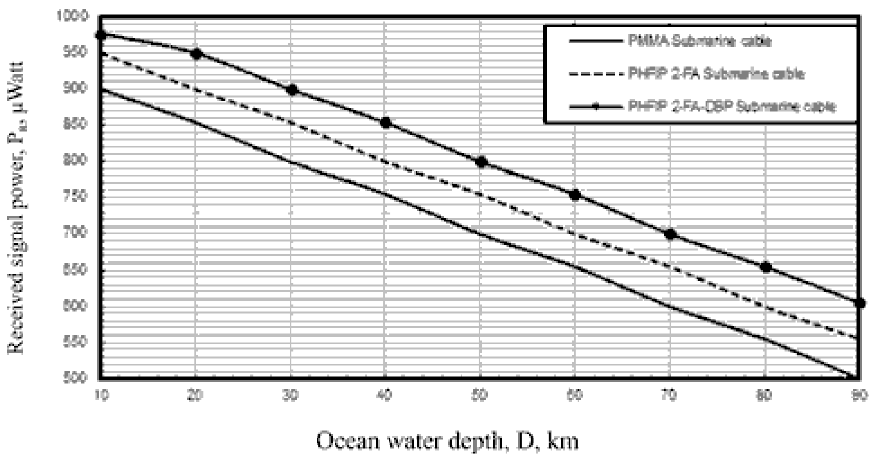

Figure 4. Received signal power in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

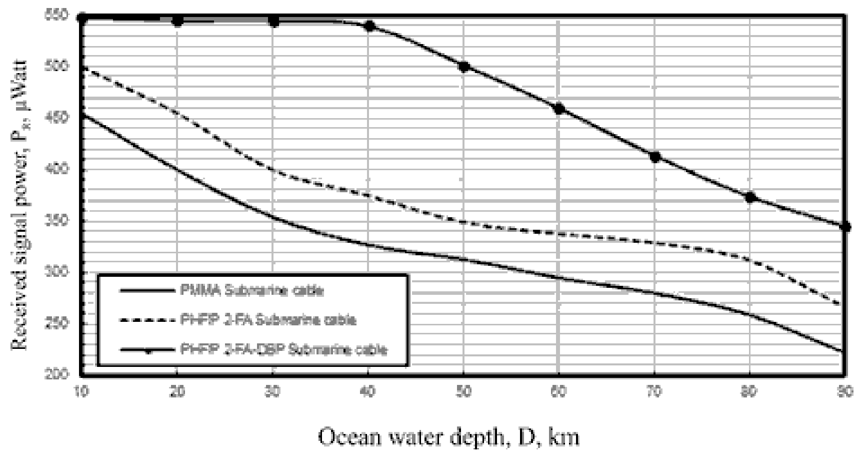

Figure 5. Received signal power in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

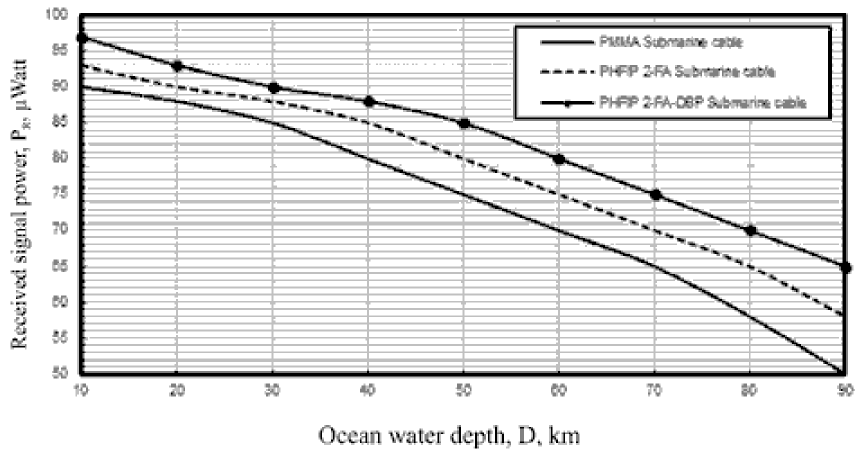

Figure 6. Signal transmission quality in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

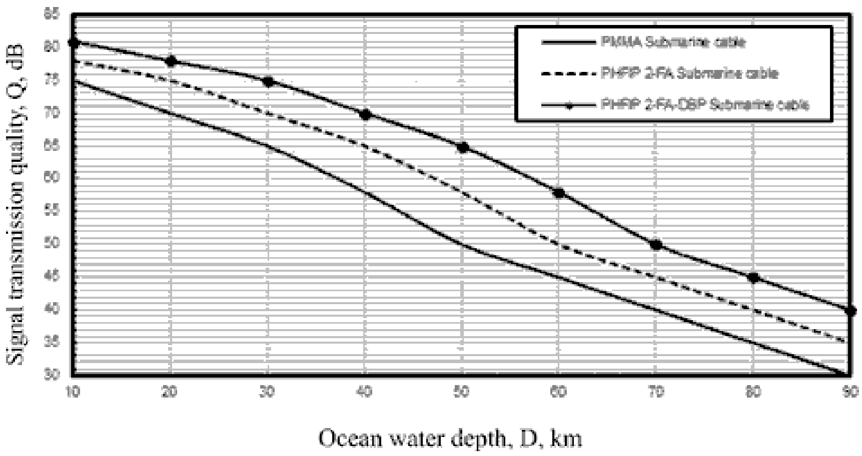

Figure 7. Signal transmission quality in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

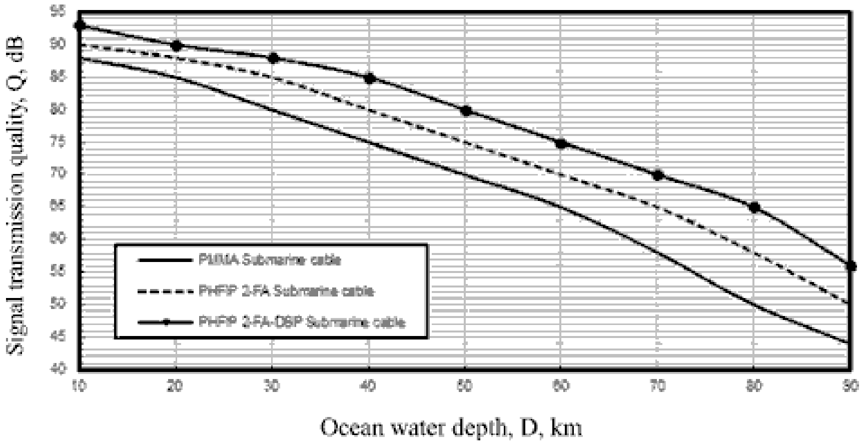

Figure 8. Signal transmission quality in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

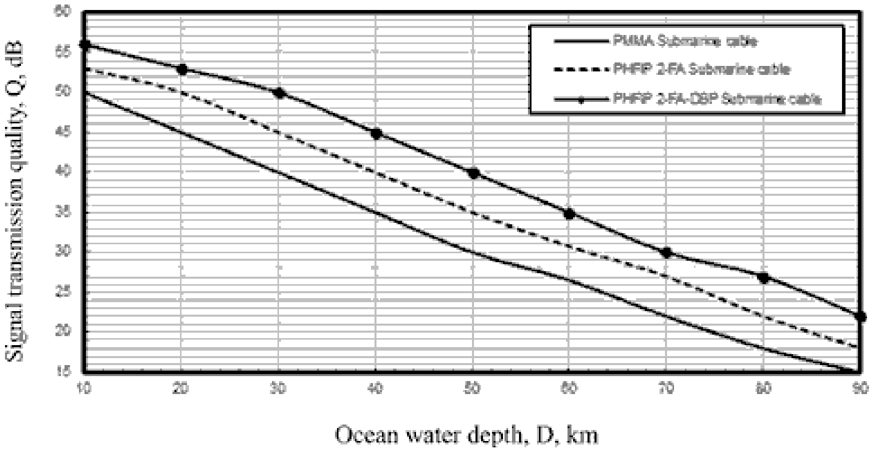

Figure 9. Signal transmission quality in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

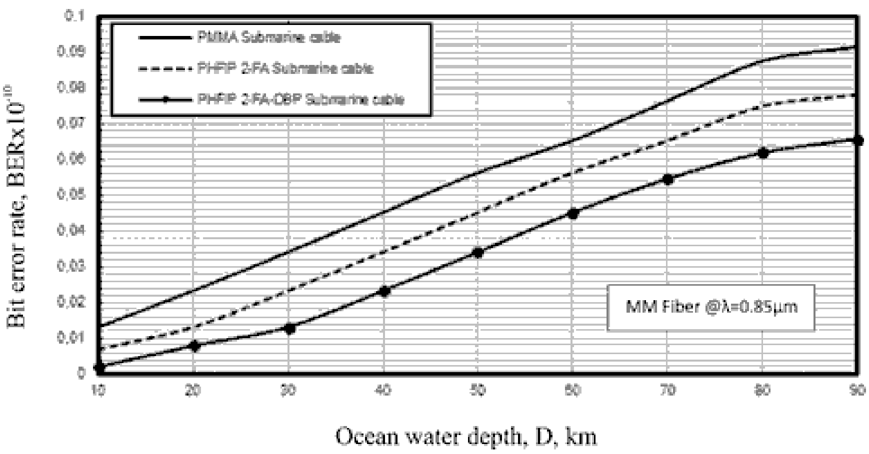

Figure 10. Bit error rate in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

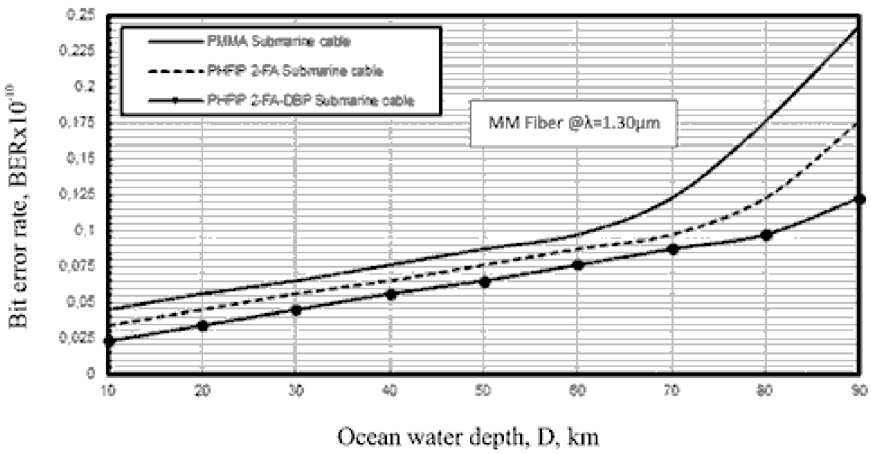

Figure 11. Bit error rate in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

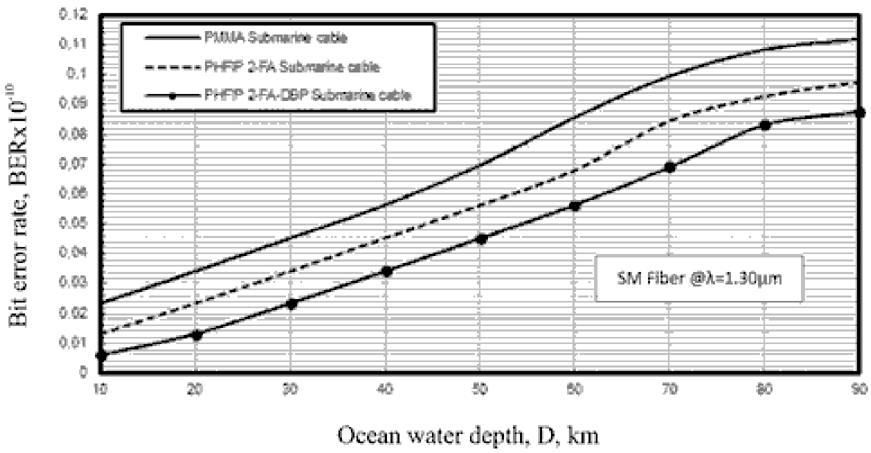

Figure 12. Bit error rate in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

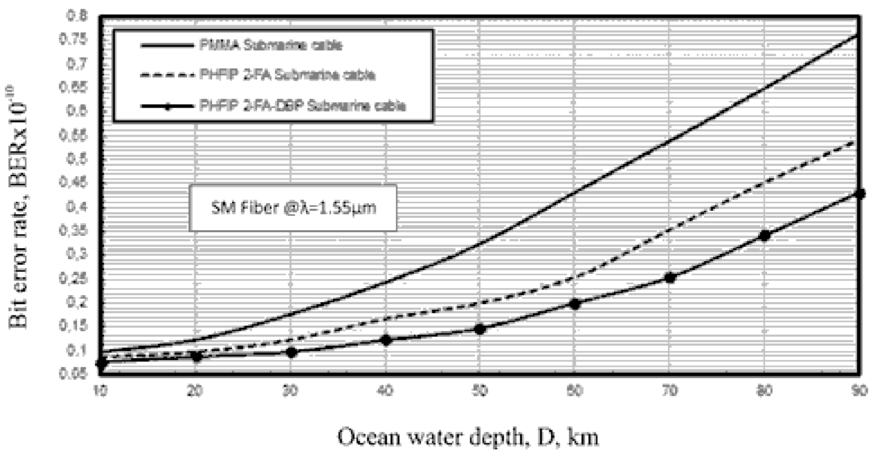

Figure 13. Bit error rate in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

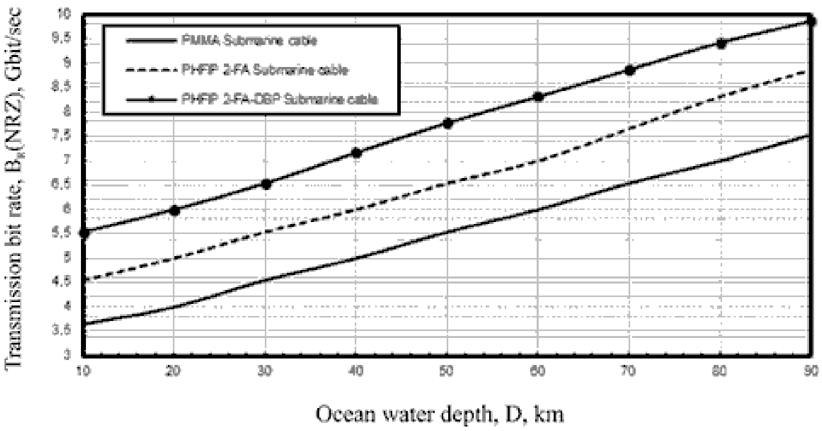

Figure 14. Transmission bit rates in relation to ocean water depth for different polymeric materials based submarine fiber cable system at the assumed set of the operating parameters.

iii) As shown in Figures (6-9) have proved that signal to noise ratio or signal transmission quality decreases with increasing ocean water depth for different polymeric materials based submarine fiber optic cable at different optical transmission windows. It is observed that PHFIP 2-FA DBP polymeric material has presented the highest signal to noise ratio or signal transmission quality compared to other materials under the same operating conditions.

iv) Figures (10-13) have indicated that bit error rate increases with increasing ocean water depth for different polymeric materials based submarine fiber optic cable at different optical transmission windows. It is observed that PHFIP 2-FA DBP polymeric material has presented the lowest bit error rate compared to other materials under the same operating conditions.

v) As shown in Figure 14. has assured that transmission bit rate increases with increasing ocean water depth for different polymeric materials based submarine fiber cable system under considerations. PHFIP 2-FA DBP polymeric material has presented the highest transmission bit rate compared to other materials under study.

4 Conclusions

In a summary, the modern fiber optic polymer submarine cable telecommunication systems planning for explosive bandwidth needs at different deployment depths have been investigated over wide range of the affecting parameters. It is theoretically observed that the increased ocean water depth, resulting in the increased transmitted signal bandwidth, and transmission bit rates for different polymeric materials based submarine optic fiber cable system under the same operating conditions. As well as it is indicated that the increased ocean water depth, leads to the decreased signal to noise ratio, received signal power and the increased bit error rate at different optical transmission windows for all polymeric materials based submarine system. Moreover it is theoretically found that PHFIP 2-FA DBP polymeric material has presented the highest transmitted signal, transmission bit rate, signal to noise ratio, received signal power and the lowest bit error rate compared to other materials under study at the same operation condition and environments. So, PHFIP 2-FA DBP polymeric material has become the best candidate polymeric material based submarine system compared to other polymeric materials in our current research.

References

Aoul-Enein, A. (1989). Termal-Dependent Chromatic Dispersion in Lightwave System. Proc. 14 the Intern. Conf. Statistics, Computer Science, Social and Demographic Research, Cairo Egypt, Vol.2, pp.195-211, March 1989.

Bakhshi, B., M. Manna, G. Mohs, D. I. Kovsh, R. Lynch, M. Vaa, E. A. Golovchenko, W. W. Patterson, B. Anderson, P. Corbett, S. Jiang, M. Sanders, H. Li, G. T. Harvey, A. Lucero, and S. M. Abbott. (2004). First Dispersion Flattened Transpacific Undersea System: From Design to Terabit/s Field Trial. J. Lightw. Technol., Vol. 22, No. 1, pp. 233–241, Jan. 2004.

Bergano, N. S. (2005). Optical Fiber Submarine Cable Systems. J. Lightwave Technol., Vol. 23, No. 12, pp. 4125-4139, Dec. 2005.

Bigo, S. (2006). Modelling of WDM Terrestrial and Submarine links for the Design of WDM Networks. Optical Fiber Communication Conference, 2006 and the 2006 National Fiber Optic Engineers Conference, pp. 1- 27, March 2006.

Charlet, G., and S. Bigo. (2006). Upgrading WDM Submarine Systems to 40 Gbit/sec Channel Bit Rate. Proceedings of the IEEE, Vol. 94, No. 5, pp. 935 - 951, May 2006.

Enein, A. A. A., F. Z. El-Halafawy, M. H. A. Hassan, A. A. Mohammed. (1989). Thermal Environmental Effects. Alex. Eng. J., Alex. Univ., Vol.28, pp.169-183, 1989.

Fleming, J. W. (1984). Dispersion in GeO_2-SiO_2 Glasses. Appl. Opt., Vol. 23, No. 24, pp. 4488-4493, Dec. 1984.

Ghosh, G., and H. Yajima,"Pressure-Dependent Sellmeier Coefficients and Material Dispersions for Silica Fiber Glass," J. Lightwave Technol., Vol.16, No.11, pp. 2002-2005, Nov. 1998.

Jeunhomme, L. B. (1983). Single-Mode Optical Fiber. Marcel Dekker, New York.

Lefrancois, M., G. Charlet, and S. Bigo. (2006). Impact of Very Large Cumulated Dispersion on Performance of 40 Gbit/s Submarine Systems Over Nonzero Dispersion Shifted Fibers. Electronics Letters, Vol. 42 No. 3, pp. 174-176, Feb. 2006.

Mohammed, A. E. A., A. N. Z. Rashed, and M. S. F. Tabour. (2011b). Transmission Characteristics of Radio over Fiber (ROF) MillimeterWave Systems in Local Area Optical Communication Networks. International Journal of Advanced Networks and Applications, Vol. 2, No. 6, pp. 876-886, May/June 2011.

Mohammed, A. E. A., M. A. Metawe'e, A. N. Z. Rashed, and A. I. M. Bendary. (2011c). Recent Progress of $LiNbO_3$ Based Electrooptic Modulators with Non Return to Zero (NRZ) Coding in High Speed Photonic Networks. International Journal of Information and Communication Technology Research, Vol. 1, No. 2, pp. 55-63, June 2011.

Mohammed, A. E. A., M. El-Halawany, A. N. Z. Rashed, and M. M. Eid. (2011a). Optical Add Drop Multiplexers with UW-DWDM Technique in Metro Optical Access Communication Networks. International Journal of Computer Science and Telecommunications (IJCST), Vol. 2, No. 2, pp. 5-13, April 2011.

Mohammed, A. E. A., M. El-Halawany, A. N. Z. Rashed, and M. M. Eid. (2011e). Optical Add Drop Multiplexers with UW-DWDM Technique in Metro Optical Access Communication Networks. International Journal of Computer Science and Telecommunications (IJCST), Vol. 2, No. 2, pp. 5-13, April 2011.

Mohammed, A. E. A., M. M. E. El-Halawany, A. N. Z. Rashed, and M. S. F. Tabour. (2011d). High Transmission Performance of Radio over Fiber Systems over Traditional Optical Fiber Communication Systems Using Different Coding Formats for Long Haul. International Journal of Computer Science and Telecommunications (IJCST), Vol. 2, No. 3, pp. 29-42, June 2011.

Mohammed, A. E. A., M. M. E. El-Halawany, A. N. Z. Rashed, and S. Hanafy. (2011f). High Performance of Plastic Optical Fibers within Conventional Amplification Technique in Advanced Local Area Optical Communication Networks," International Journal of Multidisciplinary Sciences and Engineering (IJMSE), Vol. 2, No. 2, pp. 34-42, May 2011.

Pilipetskii, A. N. (2006). High Capacity Undersea Long Haul Systems. J. Selected Topics in Quantum Electronics, Vol. 12, No. 4, pp. 484-496, Aug. 2006.

Rashed, A. N. Z. (2011a). New Trends of Forward Fiber Raman Amplification for Dense Wavelength Division Multiplexing (DWDM) Photonic Communication Networks. International Journal of Soft Computing, Vol. 6, No. 2, pp. 26-32, 2011.

Rashed, A. N. Z. (2011b). Transmission Performance Characteristics of Silica Doped and Plastic Optical Fibers in Local Area Optical Communication Networks. E-International Scientific Research Journal, Vol. 3, No. 3, pp. 156-173, July/Sep. 2011.

Rashed, A. N. Z. (2011c). Ultra High Transmission Capacity of Undersea Optical Fiber Cables for Upgrading UW-WDM Submarine Systems. Canadian Journal on Electrical and Electronics Engineering Vol. 2, No. 10, pp. 481-490, October 2011.

Rashed, A. N. Z. (2011d). Transmission Performance Characteristics of Silica Doped and Plastic Optical Fibers in Local Area Optical Communication Networks. E-International Scientific Research Journal, Vol. 3, No. 3, pp. 156-173, July/Sep. 2011.

Rashed, A. N. Z. (2011e). Transmission Performance Evaluation of Optical Add Drop Multiplexers (OADMs) in Optical Telecommunication Ring Networks. American Journal of Engineering and Technology Research, Vol. 11, No. 10, pp. 12-21, October 2011.

Rashed, A. N. Z. (2011f). Optical Add Drop Multiplexer (OADM) Based on Dense Wavelength Division Multiplexing Technology in Next Generation Optical Networks. American Journal of Engineering and Technology Research, Vol. 11, No. 11, pp. 48-61, November 2011.

Rashed, A. N. Z. (2011g). New Trends of Forward Fiber Raman Amplification for Dense Wavelength Division Multiplexing (DWDM) Photonic Communication Networks. International Journal of Soft Computing, Vol. 6, No. 2, pp. 26-32, 2011.

Rashed, A. N. Z. (2011h). Ultra High Transmission Capacity of Undersea Optical Fiber Cables for Upgrading UW-WDM Submarine Systems. Canadian Journal on Electrical and Electronics Engineering Vol. 2, No. 10, pp. 481-490, October 2011.

Rashed, A. N. Z. (2011i). High Transmission Bit Rate of Multi Giga Bit per second for Short Range Optical Wireless Access Communication Networks. International Journal of Advanced Science and Technology, Vol. 32, pp. 23-32, July 2011.

Rashed, A. N. Z. (2011j). Recent Advances of Wide Band Magneto-optical Modulators in Advanced High Speed Optical Communication System. International Journal of Engineering and Management Research (IJEMR), Vol. 2, No. 2, pp. 14-22, April 2012.

Rashed, A. N. Z. (2012). High Operation Efficiency of Semiconductor Electrooptic Modulators in Advanced Lightwave Communication Systems. International Journal of Basic and Applied Science, Vol 01, No. 01, 95-115, July 2012.

Suzuki, H., M. Fujiwara, and K. Iwatsuki. (2006). Application of Super DWDM Technologies to Terrestrial Terabit Transmission Systems. J. Lightwave Technol., Vol. 24, No. 5, pp. 1998 - 2005, May 2006.

T. Fujisawa, T. and M. Koshiba. (2011). Time Domain Beam Propagation Method for Nonlinear Optical Propagation Analysis and Its Application to Photonic Crystal Circuits. J. Lightwave Technol., Vol. 22, No. 2, pp.684-691, Feb. 2004.

Tang, J. (2001a). The Shannon Channel Capacity of Dispersion-Free Nonlinear Optical Fiber Transmission. J. Lightwave Technol., Vol. 19, No.8, pp. 1104-1109, Aug. 2001.

Tang, J. (2001b). The MultiSpan Effects of Kerr Nonlinearity and Amplifier Noises on Shannon Channel Capacity of a Dispersion-Free Nonlinear Optical Fiber," J. Lightwave Technol., Vol. 19, No.8, pp.1110-1115, Aug. 2001.

Walker, S. S. (1996). Rapid Modelling and Estimation of Total Spectral Loss in Optical Fibers. J. Lightwave Technol., Vol. 4, No.8, pp.1125-1137, 1996.